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Improved Efficiency of Solar Power Generation by Designing Converter using Passive Ripple Cancelling Circuit

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Abstract: The Power Electronic Converters (PECs) induces the ripple in the system which increases the losses hence efficiency of the system is reduced. In this paper Passive Ripple Cancelling Circuit (PRCC) is designed which is operated in parallel with the input inductor in converter to reduce the input inductor ripple current to increase average output power. The PRCC injects AC current across the output terminals of a converter that is equal and opposite to the normal converter ripple current. This will make the output current ripple ideally zero and smooth converter output voltage is obtained. The circuit requires filtering inductor winding, an auxiliary inductor, and small capacitor in parallel with the converter. The system is designed by employing CUK converter which is controlled such that input impedance of the source is always in agreement with the load impedance following the principle of Maximum power transfer theorem ensuring peak point operation of the PV array.

I. INTRODUCTION

Solar photovoltaic is emerging as a popular green form of energy. To harness electric energy from solar a power converter is employed as a regulator for obtaining the maximum output power [4-5], [7-9]. With each PV a MPPT [1-3, 10] is needed to operate it at maximum power point. However, the inherent current ripple of a switching power converter may cause significant impact on the output power [11-14], [17]. Hence, the major objective of this paper is focused on the further study of the quantitative output power reduction effect of the input current ripple of the PV energy harvesting system and on proposing a ripple cancelling technique. In this work a CUK type converter is employed to regulate the output power of the PV panel and a Passive Ripple Cancelling Circuit (PRCC) is proposed to eliminate the current ripple [6], [15-16]. The ripple in current creates filtering difficulties, control issues, output voltage noise, and other problems. Ripple reduction techniques [8-10] provide an approach for improved power converter performance. Low noise supplies are required for signal processing, high performance imaging, instrumentation equipment, and other signal to noise sensitive applications. In this paper Passive Ripple Cancelation Circuit (PRCC) is designed which is operated in parallel with the input inductor in converter to reduce the input inductor ripple current to increase average output power. The PRCC injects AC current across the output terminals of a converter that is equal and opposite to the normal converter ripple current. This will make the output current ripple ideally zero and smooth converter output voltage is obtained. A transformer connected across the converter output inductor generates a voltage of correct polarity and wave-shape that, when applied to a suitably sized inductor, automatically generates the exact cancelling current.

In literature numerous techniques [23-25] are available to minimize the ripple at output of the converter. To solve the issues related with the current ripple various techniques are follows:

Method I - Connecting bulky electrolytic capacitor across PV module and switching power converter, also called ripple filter.

Drawback: Use of electrolytic capacitor reduces lifespan of power converters.

Method II - Integrating a coupled inductor into the converters to reduce ripple, also called as ripple filter. Drawback: sensitive to coupling coefficient.

Method III - Use of interleaved n-phase control that also suffers from several problems for ripple reduction.

Drawbacks: (a) It is not possible to implement the corresponding interleaved control for a 1-ϕ converter.
(b) The zero current ripple is only achieved at d = 0.5.

Method IV – Use of PRCC.

Advantage: (a) No requirement of active circuit.

(b) Does not depend on the duty ratio or switching frequency.

This paper presents the simulation results of the PRCC in PV system using CUK Converter. Comparative results are also tabulated to study the effect of PV system connected with CUK converter employing MPPT.

II. PROPOSED SCHEME INTEGRATED WITH CUK CONVERTER

A PV cell is a basic unit optimized to give a cell output voltage of 0.5-0.6 Volts against the standard test conditions of solar insolation of 1000 W/m^2, and operating temperature of 25^{o}C. A PV module is a commercial unit with many series connected cells encapsulated within a glass frame that generates a compatible voltage to charge a 12 volts battery. Conventionally, 36 series cells are connected to give 12V battery compatible output in a commercial module. As PV array is modular in structure and can be configured for any voltage rating and power output by suitably connecting them in series parallel. The series connected cells form strings and connecting these strings in parallel forms PV Array. The PV array used in this work consists of 2 PV modules per string. Three such modules are connected in parallel to form a PV array. Thus PV array considered for simulation has total number of 06 modules. The modules which are now commercially available and used in this simulation study consists of 80 numbers of cells per module as against the 36 cells of conventional module as mentioned in previous paragraph. The 80 number of series connected cells together gives open circuit voltage of 99.4 volts. Each module is rated for 334.905 W under Standard Test Conditions (STC). The total numbers of 06 modules in the PV array together gives 2009 watts of power output. The system is simulated in MATLAB whose parameters are specified in Table1. The block diagram illustration of proposed work is shown in figure 1.

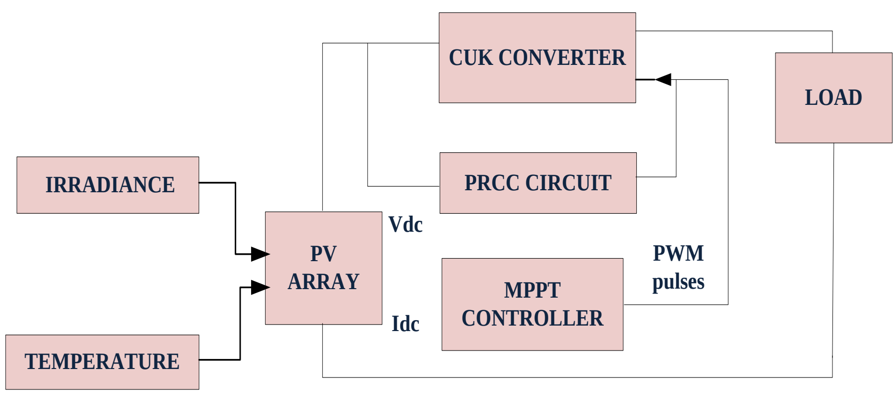

Fig 1: The proposed scheme with CUK converter with integrated PRCC

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The power electronics interface employing CUK converter is controlled such that input impedance of the source is always in agreement with the load impedance following the principle of Maximum power transfer theorem ensuring peak point operation of the PV array [15].

Table 1: Specification of PV module

Sr. No.	Parameters	Design values
1.	$P_{MAXIMUM}$	2009 watts
2.	V_{OC}	99.4 volts
3.	I_{SC}	27 amps
4.	I_{MP}	24.21amps
5.	V_{MP}	83volts

The switching operation of the CUK converter gives rise to ripples in the input and output which is mitigated by employing PRCC circuit. Rest of the scheme is conventional and found in the referred literature. The environmental conditions of solar insolation and temperature makes PV array output variable and each set of them gives rise to unique peak power point operation. It is therefore under the varying solar insolation and temperature a power electronics interface need be introduced which can match input resistance of the source to load resistance all the time, so as to ensure global peak operation.

III. PERFORMANCE BEHAVIOR OF BOOST CONVERTER WITHOUT PRCC

Behavior of Boost converter without PRCC circuit by varying solar insolation from 100 W/m^2 to 1000 W/m^2 is analyzed. Simulation result shown in Figure 2, depicts the P-V curve variation of boost converter from 100 W/m^2 to 1000 W/m^2. The performance behavior of PV array for varying solar insolation is shown in Figure 2. As the solar insolation gets changed, the MPPT algorithm makes PV array to settle at new peak corresponding to new irradiance as visible from Figure. 3. The PV voltage variation also passes through stages of varying solar insolation until it eventually settles to voltage Vmax of 83 volts corresponding to 1000 W/$m^{2,}$ as shown in Figure 4.

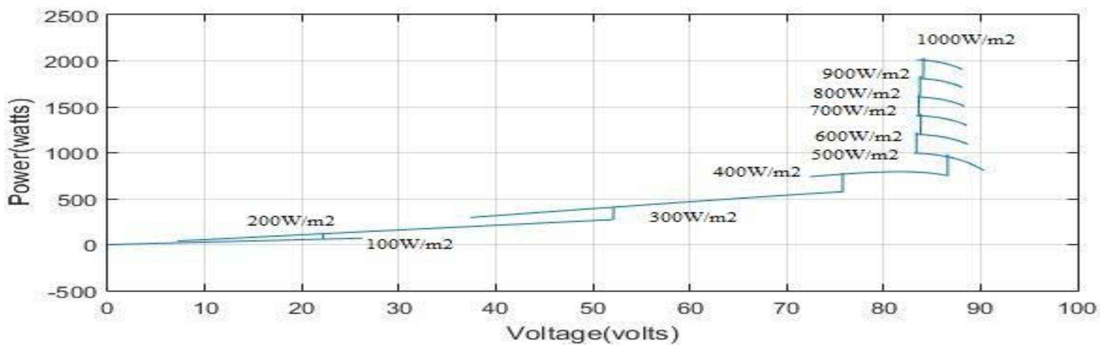

Figure 2 P-V curve variations by varying irradiance level

Fig 2, shows the PV power v/s PV voltage variation curve by varying irradiance level from 100W/m^2 to 1000W/m^2. This Fig 2 shows the P_{max} value tracks by MPPT using in boost converter topology at different irradiance level. MPP is possible only at high irradiance level.

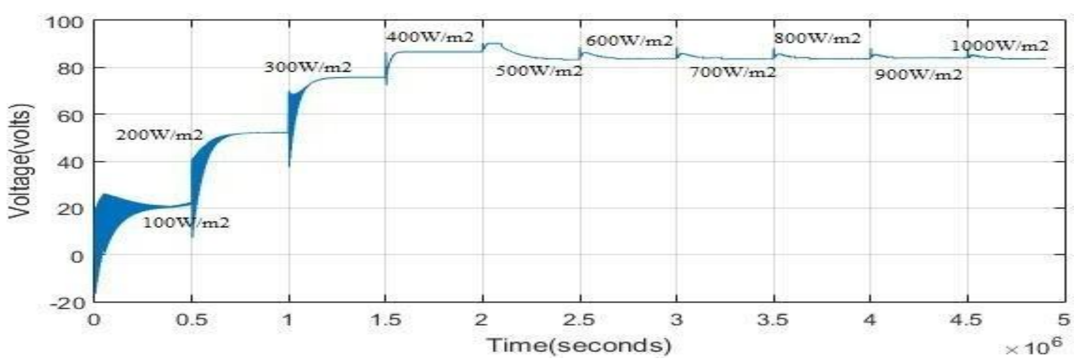

Figure 3 PV Voltage variation with respect to time for varying irradiance

Fig 3 shows the PV Voltage variation with respect to time for varying irradiance level. At low irradiance level V_{max} value is not achieved, but by increasing the value of irradiance level in Boost converter topology V_{max} value can be achieved.

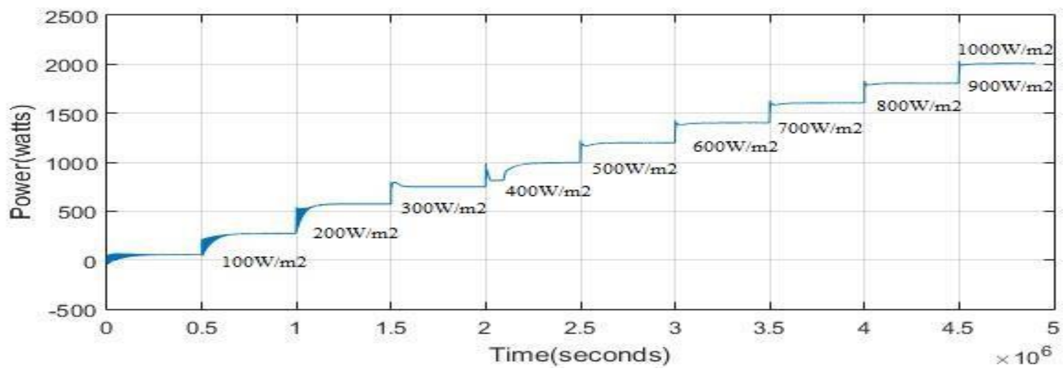

Figure 4 PV power variation with respect time by varying irradiance value

Fig 4 shows the PV power variation with respect to time by varying irradiance level in Boost converter topology. P_{max} value can be achieved at high value of irradiance level.

IV. PERFORMANCE BEHAVIOR OF CUK CONVERTER WITHOUT PRCC

Behavior of CUK converter without PRCC circuit by varying solar insolation from 100 W/m^2 to 1000 W/m^2 is analyzed. Simulation result shown in Figure 5, depicts the P-V curve variation of proposed model from 100 W/m^2 to 1000 W/m^2. The performance behavior of PV array for varying solar insolation is shown in Figure 5. As the solar insolation gets changed, the MPPT algorithm makes PV array to settle at new peak corresponding to new irradiance as visible from Figure. 6. The PV voltage variation also passes through stages of varying solar insolation until it eventually settles to voltage Vmax of 83 volts corresponding to 1000 $W/m^{2,}$ as shown in Figure 7.

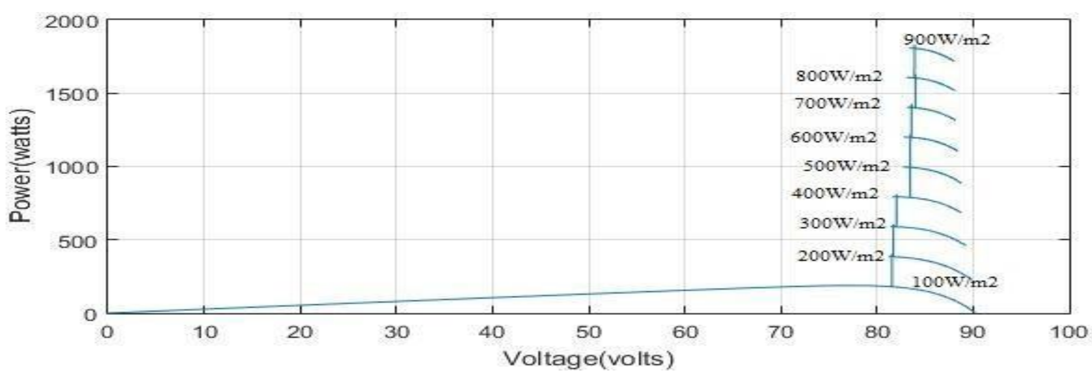

Fig 5: P-V curve of proposed module without PRCC

Figure 6 shows the PV voltage variation with respect to time of proposed module without PRCC. From this Figure it is concluded that MPP tracks at any value of irradiance level by employing MPPT in CUK converter topology. Figure 7 shows the PV power variation with respect to time of proposed module without PRCC. From this Figure it is concluded that MPP tracks Pmax at any value of irradiance level by employing MPPT in CUK converter topology.

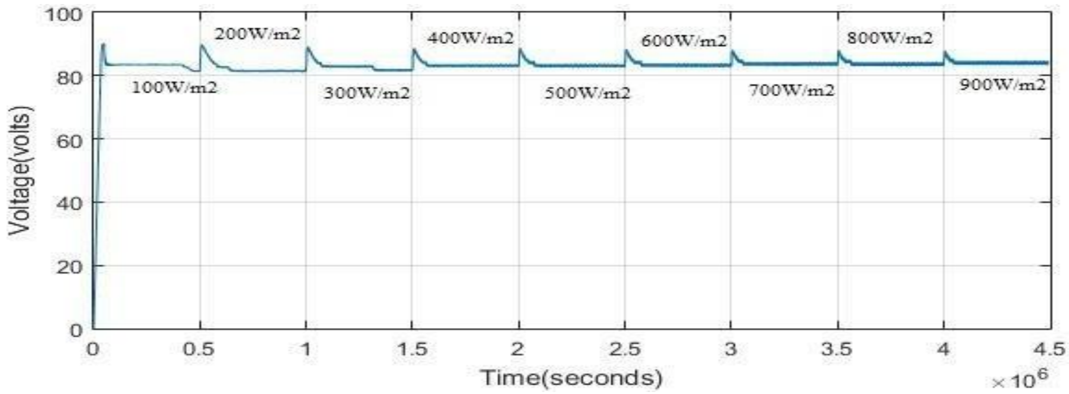

Fig 6: PV voltage variation with respect to time curve of proposed module without PRCC

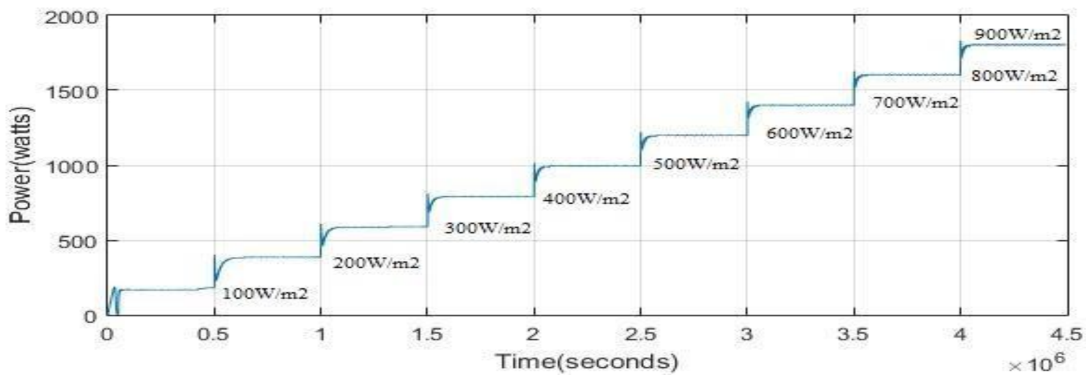

Fig 7: PV power variation curve with respect to time variation curve of proposed module without PRCC

The MPPT efficiency of BOOST and CUK converter without PRCC circuit is analyzed in the section III and IV in terms of irradiance, similarly performance also tested on different temperature and at different load . In Table 2 tracking efficiency of both the converter circuits are presented.

Table 2: Performance behavior of Boost Converter and CUK converter circuit without PRCC

S. No.	**Parameter**	**Boost Converter**	**CUK converter**
1.	By varying the value of load resistance	Maximum power tracking will improved.	Maximum power point is at P_{MAX} value in all the cases of load resistance value
2.	By varying irradiance value	Maximum power tracks only at high irradiance level.	Maximum power tracking at low and high values of irradiance level.
3.	By varying temperature	Maximum power goes on Decreases by varying the value of temperature.	Same case as Boost converter case.

From above table, it is concluded that CUK converter is better than Boost converter. Hence for PV energy system CUK converter gives higher efficiency than the Boost converter.
By employing PRCC circuit integrated with CUK converter circuit ripple current reduces and power output from the PV energy system increases and efficiency of the system will increases.

IV. COMPARATIVE ANALYSIS WITH AND WITHOUT PRCC

The effectiveness of the proposed PRCC is verified by connecting it across the CUK converter. Table 3 shows the value of parameters with and without PRCC circuit at 1000W/m2. From table 3, it is concluded that by varying the value of irradiance level variation in the P_{MAX} and V_{MAX} value is very fewer. Due to the use of PRCC circuit doesn't affects the duty ratio of the converter. Table 4 and 5 shows the performance of CUK converter with and without PRCC.

Table 3: Result analysis of the CUK converter with or without PRCC in terms of P_{MAX} output and the V_{MAX}

Irradiance level at temperature 25deg.C	PV panel characteristic		Proposed model without PRCC circuit characteristic		Proposed model with PRCC circuit characteristic	
	P_{MAX}(Watts)	V_{MAX}(Volts)	P_{MAX}(Watts)	V_{MAX}(Volts)	P_{MAX}(Watts)	V_{MAX}(Volts)
1000W/m2	2009W	83V	2003W	84.53V	2004W	84.36V
800W/m2	1607W	82.92V	1603V	84.09V	1609W	83.91V

Table 4: Result analysis of CUK converter with or without PRCC at 1000 W/m^2

Sr. No.	Irradiance level 1000 W/m^2 and 25^{0}C	Proposed model without PRCC	Proposed model with PRCC
1.	P_{PV}	2003watts	2004watts
2.	I_{PV}	23.01amps	23.76amps
3.	V_{PV}	84.53volts	84.36volts
4.	V_O	139.5volts	140.9volts
5.	P_O	1945watts	1987watts
6.	I_O	13.56amps	14.09amps
7.	(I_L)input	5.025amps	4.891amps

Table 5: Result analysis of CUK converter with and without PRCC at 800 W/m^2

Sr. No.	Irradiance level 800 W/m^2 and 25^{0}C	Proposed model without PRCC	Proposed model with PRCC
1.	P_{PV}	1603watts	1609watts
2.	I_{PV}	19.07amps	19.21amps
3.	V_{PV}	84.09volts	83.91volts
4.	V_O	124.6volts	125.9volts
5.	P_O	1553watts	1585watts
6.	I_O	12.46amps	12.591amps
7.	(I_L) input	3.263amps	3.144amps
8.	(I_L) output	3.262amps	3.143amps

Input inductor ripple current without PRCC circuit is 5.025A and with PRCC circuit it becomes to 4.891 A at 1000 W/m2 and 25^{0}C. Percentage decrease in ripple content of input inductor is 2.667%. From table 3, power output at 1000 W/m^2 is 1945 W without PRCC and 1987 watt with PRCC circuit. That means output power increased 2.159%.

From table 3, irradiance value is 800 W/m2 and temperature value is 25 deg. C. The value of input inductor ripple current is 3.263A without PRCC circuit and it becomes 3.143A with PRCC circuit. That percentage decrease in input inductor ripple current 3.677% and the output power increase from 1553W to 1585W by using PRCC circuit. That is percentage increase in output power 2.06%. Hence by using PRCC circuit ripple content will reduced then the value of output power increases which will increases the efficiency of the PV energy system.

V. CONCLUSION

The Proposed scheme i.e. PRCC (Passive Ripple Cancelling Circuit) integrated with CUK converter is employed in PV energy system to reduce current ripple for the purpose of increasing power output and also efficiency of the system. As the ripples are reduced in PV energy system, average power output from the PV energy system increases then efficiency of the system will also increases. By employing DC-DC converter and MPPT (maximum power point tracking) system in the PV energy system output power increases, but due to switching of the main converter output power reduces. To maximize the output power from the PV energy system using of CUK converter which is having step up and down capability of voltage and current ripples must be eliminated. Integrating PRCC (Passive ripple cancelling circuit) across the input inductor, we can reduce the ripple current and hence power delivered by the PV energy system to the load is increases which will improve system efficiency.

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